Coupling of Microwave Pulses to Complex Enclosures: Analytical and Numerical Modeling and Experiments

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Abstract—Our objective is to understand the coupling of pulsed high-frequency radiation into complex structures through one or more routes of ingress, and to predict the induced voltages on objects located inside the enclosure. The deterministic study of such scenarios is usually computationally expensive and incapable of capturing the extreme sensitivity to scattering details. We develop a hybrid computational and statistical model to understand coupling and reverberation of the wave energy that dwells inside a complex enclosure. The model assumes minimal information about the enclosure, in the same spirit as the Random Coupling Model (RCM), which has found great success in providing a statistical characterization for wave chaotic systems in the frequency domain. The computational approach captures the details of the incident waves and coupling effects, and combines it with a stochastic Green's function approach to predict the wave distributions inside the enclosure. In addition, the RCM can be transformed into the time-domain and generalized to include early-time short-orbit transmission path effects between the ports, and the inclusion of arbitrary nonlinear or time-varying port load impedances. We have conducted short-pulse time-domain illumination experiments on a variety of wave chaotic enclosures with different types of aperture coupling. We compare the results of the hybrid model to the experimental data and generally find good agreement.

Keywords-Electromagnetic coupling, Random Coupling Model, Time-domain measurements.

I. INTRODUCTION

The Random Coupling Model (RCM) has successfully treated the statistical electromagnetic properties of complex enclosures in the short-wavelength limit [1]. It has been extended to treat the effects of short orbits between ports [2], and the effects of finite radiation efficiency of the ports [3], as examples. We are now concerned with the question of how radiation couples into complex enclosures through a variety of apertures, and then how that radiation reverberates and delivers energy to ports inside the enclosure. Sensitive electronic components inside the enclosure can be treated as one such port.

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II. HYBRID RCM / STOCHASITC GREENS FUNCTION MODEL

Our approach is to join a numerical treatment of pulsed wave energy impinging on the enclosure and finding its way through apertures, with a stochastic Green function numerical model [4] for fields inside the enclosure that is inspired by the RCM. At its heart, our hybrid approach integrates full wave, high fidelity solutions of subsystems (i.e. apertures and electronics of interest) occupying portions of the domain [5], with the RCM effectively simulating the large volume separating the fully-modeled subsystems.

III. EXPERIMENTS

Experiments have been carried out both in the frequency domain and time domain. A broadband horn antenna is used to illuminate various structures, and a short-dipole measurement port is located inside the enclosure. Frequency domain 2-port S-parameter measurements are performed with a network analyzer. A time-domain version of the same experiment is also performed with an arbitrary waveform generator attached to the antenna and an oscilloscope attached to the short dipole.

We compare statistical properties of induced voltages in the target dipole in both the frequency and time domains.

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